iJRASET
International Journal For Research in Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VI **Month of publication:** June 2019

DOI: http://doi.org/10.22214/ijraset.2019.6349

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VI, June 2019- Available at www.ijraset.com

Application of STATCOM in Renewable Energy Sources for Power Quality Improvement

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***Abstract:** In the present trend, there is widespread use of digital or microprocessor controlled devices. Whatever the case, power quality problems may disrupt operations. According to the IEEE definition, power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment. In recent trends in electrical market, most of the electronic devices are more sensitive and may not operate properly when small variations or disruptions in the electrical supply occurs. Various power quality issues that may damage the sensitive equipment are voltage sag (or dip), very short interruptions, long interruptions, voltage spike, voltage swell, harmonic distortion, voltage fluctuation and noise. To function properly, electronic devices require voltage to flow within a consistent range. Power surges, sags, transients and momentary interruptions can cause voltage to fluctuate outside this range. Based on the above power quality issues and survey of different FACTS devices we would be proposing a custom power device called STATCOM. STATCOM will be developed in MATLAB software for poc (proof of concept). On top of that, we have a plan to replace Hysteresis controller with Fuzzy logic controller, which can be implemented for closed loop testing to reduce the error and increase the gain margin and proved in the simulation results.*

***Keywords:** Power quality, wind generating system (WGS), facts devices, shunt controllers*

I. INTRODUCTION

In professional literature, there are described many different ways to “isolate” sources from disturbances introduced by the nonlinear loads and vice versa. For example to compensate reactive and higher harmonics currents, produced by the non- linear loads, STATCOM (Static Compensator) can be used. In those systems (independent with control algorithm) there is need to extract, from measured load or source currents (it depends if control algorithm is in open or closed loop), compensating components, therefore the filtration quality is as good as well it is possible to extract compensating components and shape them.

A Flexible AC Transmission System (FACTS) is an ac transmission system incorporating power electronic-based or other static controllers which provide better power flow control and enhanced dynamic stability by control of one or more ac transmission system parameters (voltage, phase angle. and impedance).

In general, FACTS controllers can be divided into three categories:

1) Series controllers
2) Shunt controllers
3) Combined series-shunt controllers

Among FACTS controllers, the shunt controllers have shown feasibility in term of cost effectiveness in a wide range of problem-solving applications from transmission to distribution levels. For decades, it has been recognized that the transmittable power through transmission lines could be increased, and the voltage profile along the transmission line could be controlled by an appropriate amount of compensated reactive current or reactive power. Moreover, the shunt controller can improve transient stability and can damp power oscillation during a post-fault event. Using a higher-speed power converter, the shunt controller can further alleviate or even eliminate the flicker problem.

The shunt controller basically consists of three groups.

a) Static variable compensator (SVC)
b) Static synchronous compensator (STATCOM)
c) Synchronous generator (SSG) or STATCOM with energy-storage system (ESS)

The paper is organized as follows. The Section II introduces the shunt controllers.. The Section III introduces the . The Section IV describes the topology for power quality improvement. The Sections V, VI, VII de- scribes the control scheme, system performance and conclusion respectively.

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II. SHUNT CONTROLLERS

Among FACTS controllers, the shunt controllers have shown feasibility in term of cost effectiveness in a wide range of problem-solving applications from transmission to distribution levels. For decades, it has been recognized that the transmittable power through transmission lines could be increased, and the voltage profile along the transmission line could be controlled by an appropriate amount of compensated reactive current or reactive power. Moreover, the shunt controller can improve transient stability and can damp power oscillation during a post-fault event. Using a higher-speed power converter, the shunt controller can further alleviate or even eliminate the flicker problem.
The shunt controller basically consists of three groups.
They are explained briefly in further with suitable diagrams.

A. Static Variable Compensator (SVC)

A static VAR compensator is a parallel combination of controlled reactor and fixed shunt capacitor shown in the figure below. The thyristor switch assembly in the SVC controls the reactor. The firing angle of the thyristor controls the voltage across the inductor and thus the current flowing through the inductor. In this way, the reactive power draw by the inductor can be controlled.
The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. It improves the system stability and system power factor. Most commonly used SVC scheme are as follows.

1) Thyristor-switched capacitor (TSC)
2) Thyristor-controlled reactor (TCR)
3) Self Reactor (SR)
4) Thyristor controlled reactor – Fixed capacitor (TCR-FC)
5) Thyristor-switched capacitor – Thyristor controlled reactor (TSC-TCR)

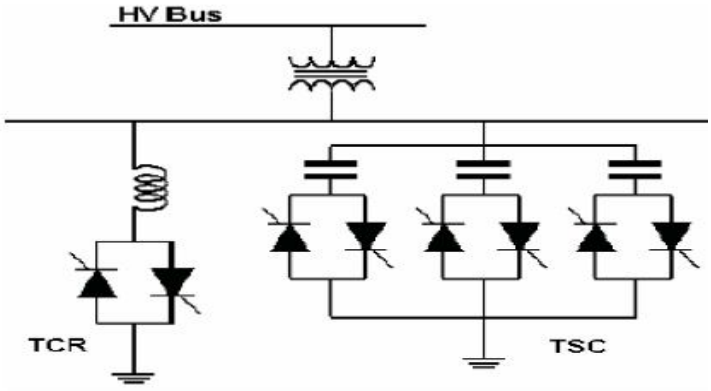


Fig. 1 Schematic diagram of SVC

a) Advantages of Static VAR Compensator
b) It increased the power transmission capability of the transmission lines.
c) It improved the transient stability of the system.
d) It controlled the steady state and temporary over voltages.
e) It improved the load power factor, and therefore, reduced line losses and improved system capability.

Static VAR compensator has no rotating parts and is employed for surge impedance compensation and compensation by sectionalizing a long transmission line.

B. Static Synchronous Compensator (STATCOM)

STATCOM is one of the most important shunt FACTS controllers, which have broad applications in electric utility industry. STATCOM has played an important role in power industry since 1980s and recognized to be one of the key technologies in future power system. STATCOM is based on the principle that a voltage source inverter generates a controllable AC voltage source behind a reactance so that the voltage difference across the reactance produces active and reactive power exchange between the STATCOM and the transmission network line in a similar manner of a synchronous condenser, but much more rapidly. Figure below shows the schematic configuration of STATCOM.

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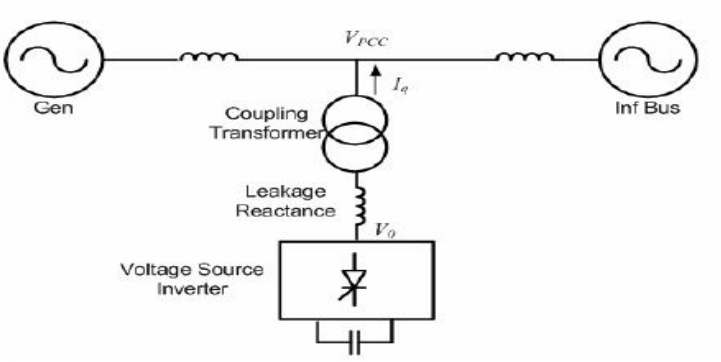


Fig. 2 Schematic diagram of STATCOM

Compared to SVC and other conventional reactive power compensators, STATCOM has several advantages. STATCOM has the ability to maintain full output current range even at a very low system voltage. STATCOM uses a converter based var generator and functions as a shunt connected synchronous voltage source. This is fundamentally different from SVC, which, with the thyristor-controlled reactors and thyristor-switched capacitors, functions as a shunt connected, controlled reactive admittance. This basic operation difference (voltage source versus reactive admittance) accounts for the STATCOMs overall superior functional characteristics, performance and greater application flexibility than SVC.

C. Synchronous Generator (SSG) or STATCOM with Energy-Storage System (ESS)

STATCOM with storage have several advantages for operation and control of power system . Some of these applications include reactive and active power control, stability enhancement, system security enhancement, integration of renewable generation, avoidance of new transmission line construction, power flow congestion management, and providing control mechanism for remedial action schemes.

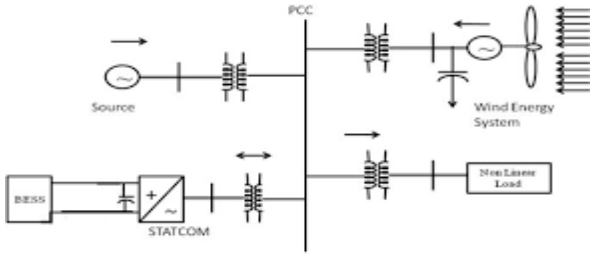


Fig. 3 Schematic diagram of STATCOM with ESS

Wind power generation is one of the important renewable energy, which need to be controlled given inherent intermittency. Power electronic interface have proven an important facilitator in integrating renewable energy. Due to the high wind power generation penetration into the grid network, the power quality of the wind generator and their continuous long-term operation becomes significantly important. The pulsating nature of the wind turbine torque produces oscillatory active and reactive power outputs at blade-passing frequencies. This oscillatory nature worsens the power quality of the wind farm in terms of voltage fluctuation at the PCC and sometimes causes damage the generators connected to the network.

The benefit of using a battery in parallel to the wind turbine is that it gives the chance to produce always as much power as possible and store the energy that cannot be injected to the grid. A battery connected to the STATCOM can be the best solution to maximize the power that can be injected in a weak network in a distributed generator (DG) system . The generator can be sized to produce more power than the maximum power because the excessive power can be absorbed by the battery. For a case where this situation will be possible but not probable, the BESS can be used as a dump load to absorb the power.

STATCOM + BESS unit can be applied to load leveling, saving energy at peak demand, minimizing sub synchronous oscillations, enhancing transient and dynamic stability. Another advantage of using STATCOM + BESS is that the DC link capacitor value can be reduced enormously. For certain applications, only a small capacitor would be sufficient to smooth the battery DC current which is an eminent feature of integrating battery energy storage system (BESS) with STATCOM.

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III. TOPOLOGY FOR POWER QUALITY IMPROVEMENT

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid volt- ages are sensed and are synchronized in generating the cur- rent command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Fig. 4. The grid connected system in Fig.4, consists of wind energy generation system with STATCOM.

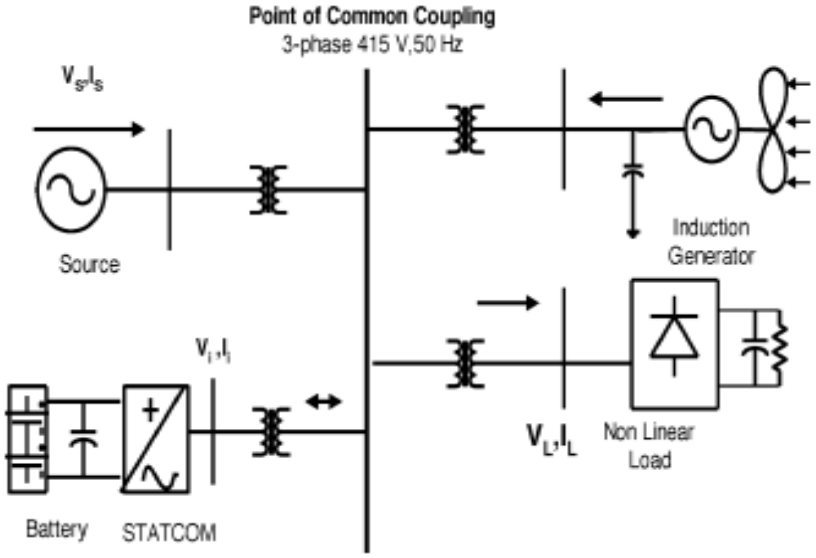


Fig. 4 Grid connected system for power quality improvement

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in Fig 5.

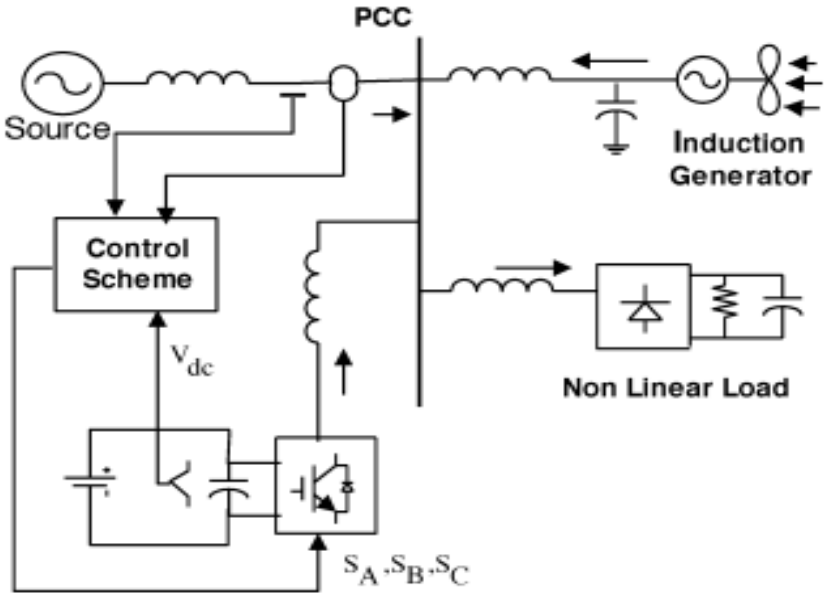


Fig. 5 System operational scheme in grid system

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Volume 7 Issue VI, June 2019- Available at www.ijraset.com

IV. CONTROL SCHEME

A. Hysteresis Controller

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signal for STATCOM operation. The control system scheme for generating the switching signals to the STATCOM is shown in Fig.6.

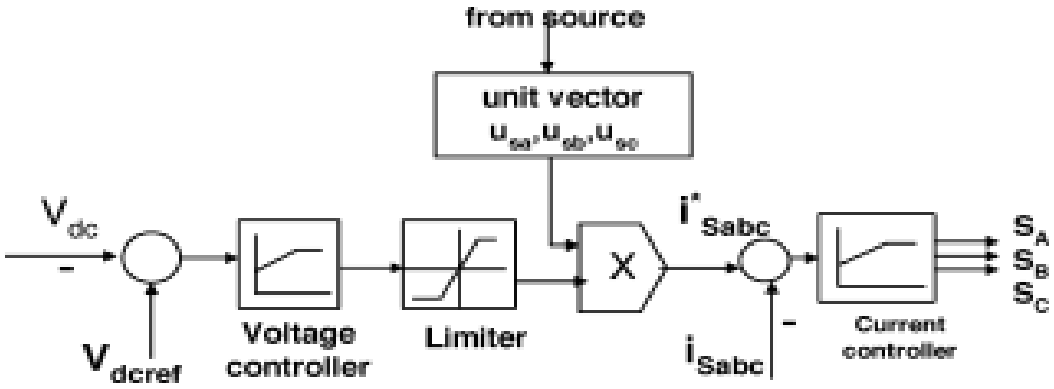


Fig. 6 Control system scheme

The control algorithm needs the measurements of several variables such as three-phase source current , DC voltage, inverter current with the help of sensor. The current control block, receives an input of reference current and actual current are subtracted so as to activate the operation of STATCOM in current control mode.

B. Fuzzy Logic Controller

The concept Fuzzy Logic was formalized by the professor Lotfi Zadeh at University of California at Berkeley in 1965. Using the rule-based structure of FL, break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. Creating FL membership functions that define the meaning (values) of Input /Output terms used in the rules. Create the necessary pre- and post-processing FL routines. Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained. The membership function is a graphical representation of the magnitude of participation of each input. It associates a weighting with each of the inputs that are processed, define functional overlap between inputs, and ultimately determines an output response. Fuzzy logic is a super set of conventional (Boolean) logic .

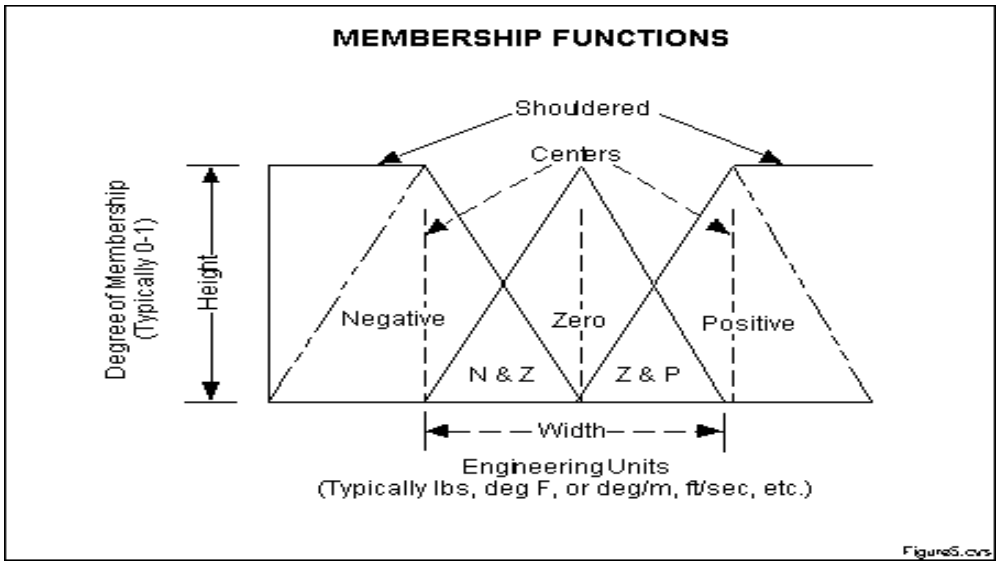
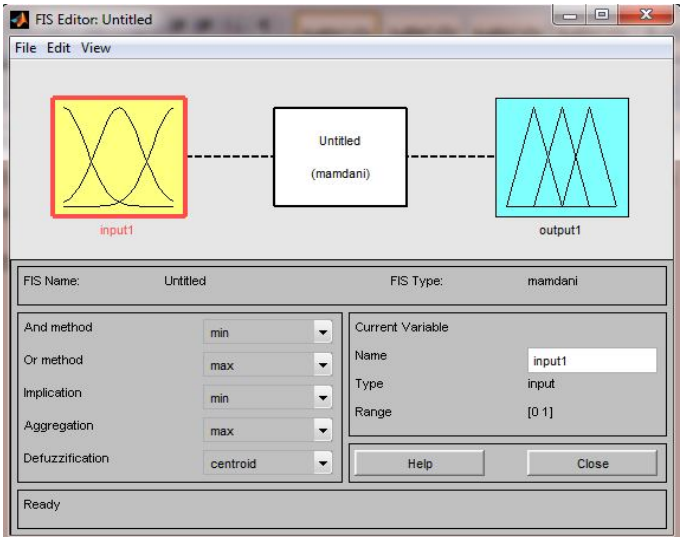


Fig. 7 Different types of membership functions

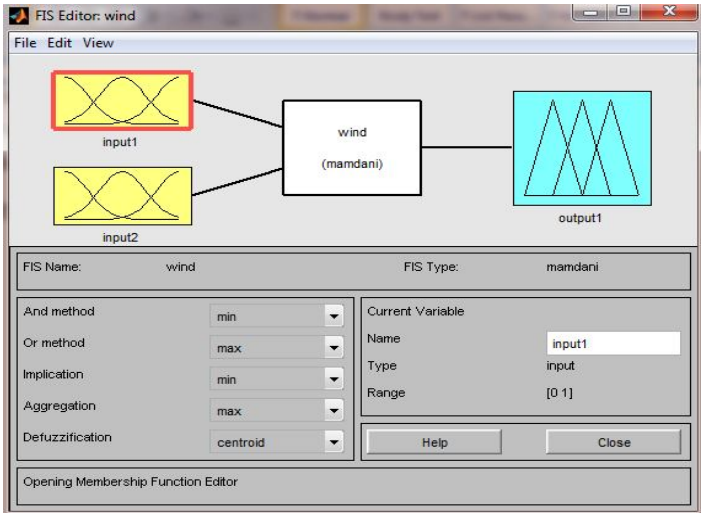
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Step by step procedure for implementing fuzzy logic controller

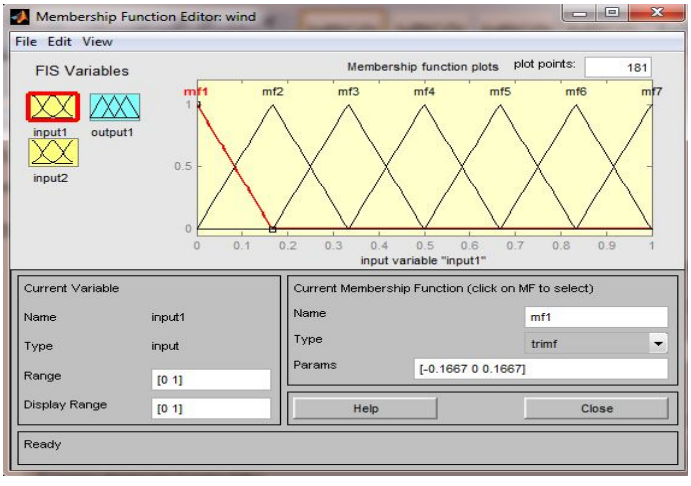
1) Implementation of Fuzzy in STATCOM



2) Added two inputs

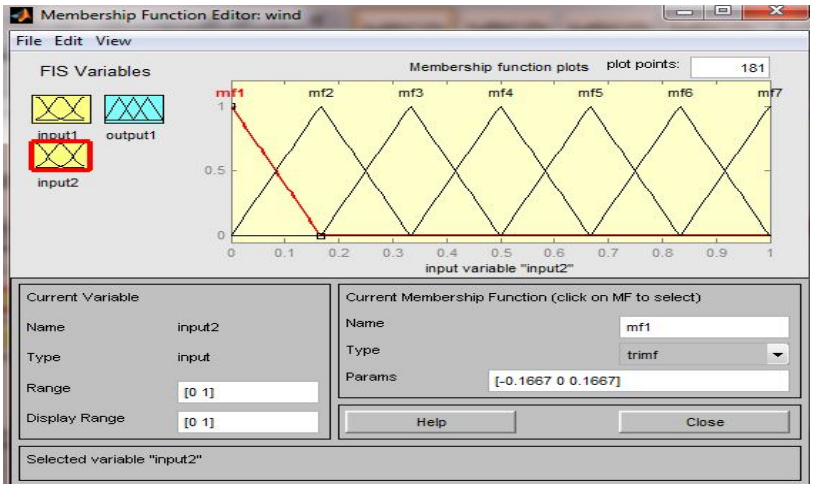


3) Membership functions of input 1

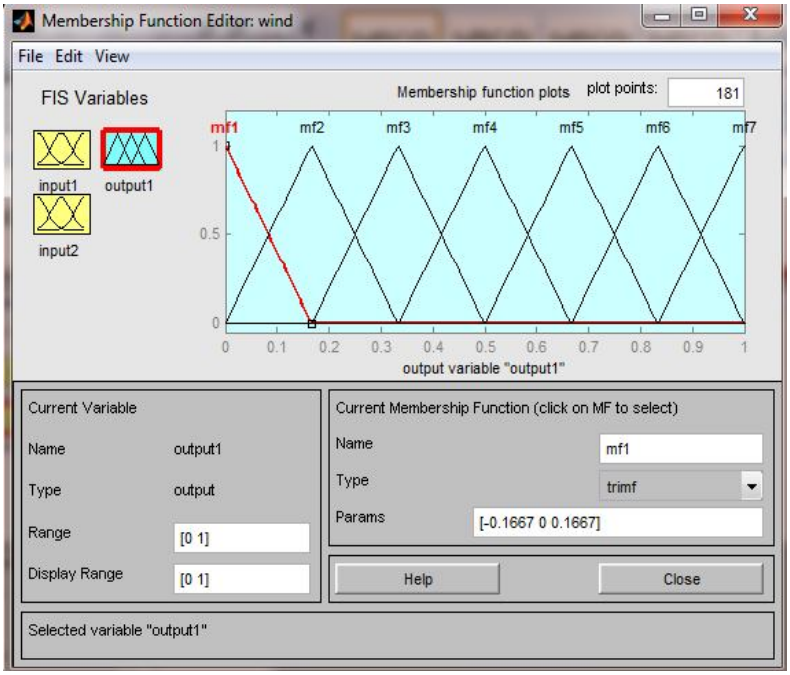


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4) Membership functions of input 2



5) Membership functions of output



Fuzzy rules are used within fuzzy logic systems to infer an output based on input variables.

Input1\input2	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	PM	PS	Z
NM	PL	PL	PL	PM	PS	Z	NS
NS	PS	PM	PM	PS	Z	NS	NM
Z	PL	PM	PS	Z	NS	NM	NL
PS	PM	PS	Z	NS	NM	NM	NL
PM	PS	Z	NS	NM	NL	NL	NL
PM	Z	NS	NM	NL	NL	NL	NL

NL- Negative long, NM-Negative medium, NS-negative small
PL-Positive long, PM-Positive medium, PS-Positive small

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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V. SYSTEM PERFORMANCE

The proposed control scheme is simulated using SIMULINK model of STATCOM with fuzzy logic controller

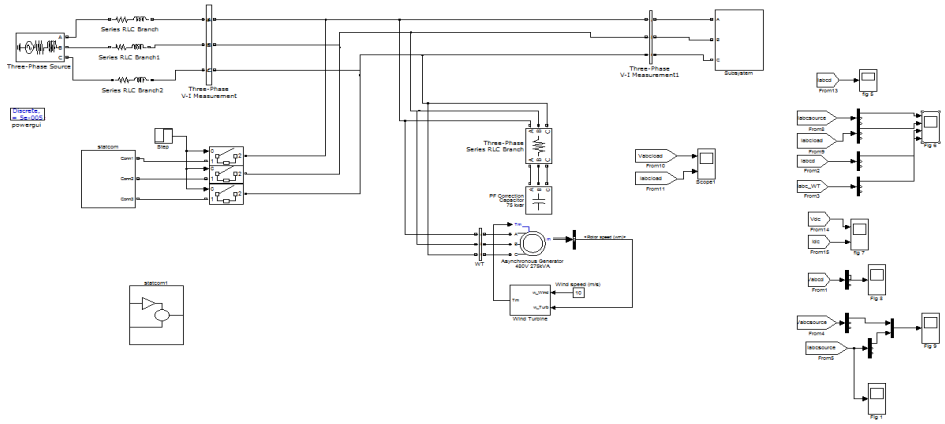


Fig 8 Simulink diagram of proposed system

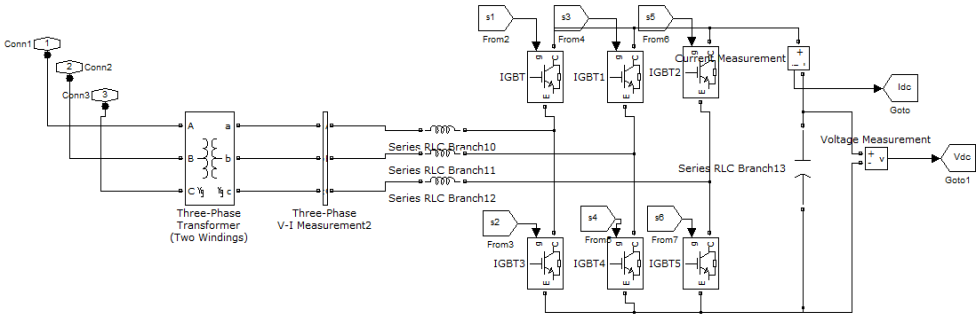


Fig 9 STATCOM-BESS

In fig 9, STATCOM-BESS is given. The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also control the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation. The battery is connected in parallel to the dc capacitor of STATCOM .The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.

The proposed control scheme is simulated using SIMULINK in power system block set. The system parameter for given system is given Table I

Table I System Parameters

S. No.	Parameters	Ratings
1	Grid Voltage	3-phase, 415 Volts, 50 Hz
2	Induction motor/generator	3.35kVA, 415V, 50Hz, Rs=0.016Ω, Ls=0.06H, Rr=0.015Ω, Lr=0.06H, Lm=3.5H, speed=1800rpm, pole=4
3	Line series inductance	0.05mH
4	Inverter parameters	DC Link voltage=799.5 V, DC Link Capacitance=100μF, Switching frequency= 2kHz
5	IGBT rating	Collector voltage=1200V, Forward current=50A, Gate voltage=20V, Power dissipation=310W
6	Load parameter	Non-linear load 25kW

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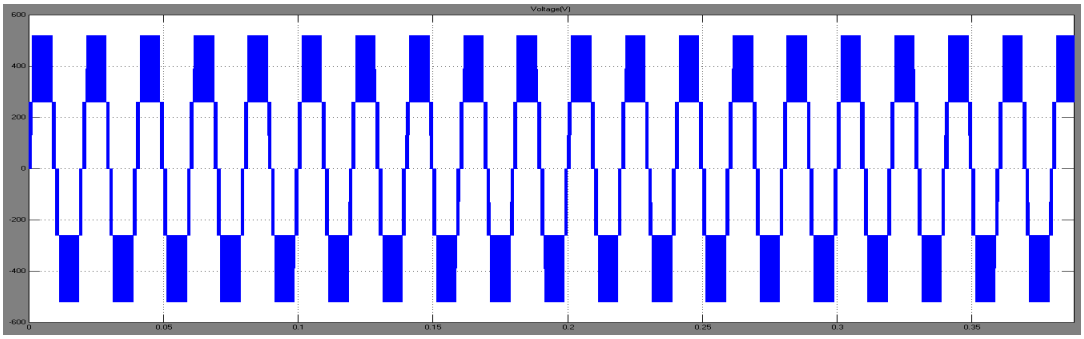


Fig.10 STATCOM output voltage

It is observed that the source current on the grid is affected due to the effects of nonlinear load and wind generator, thus purity of waveform may be lost on both sides in the system. The inverter output voltage under STATCOM operation with load variation is shown in Fig.10

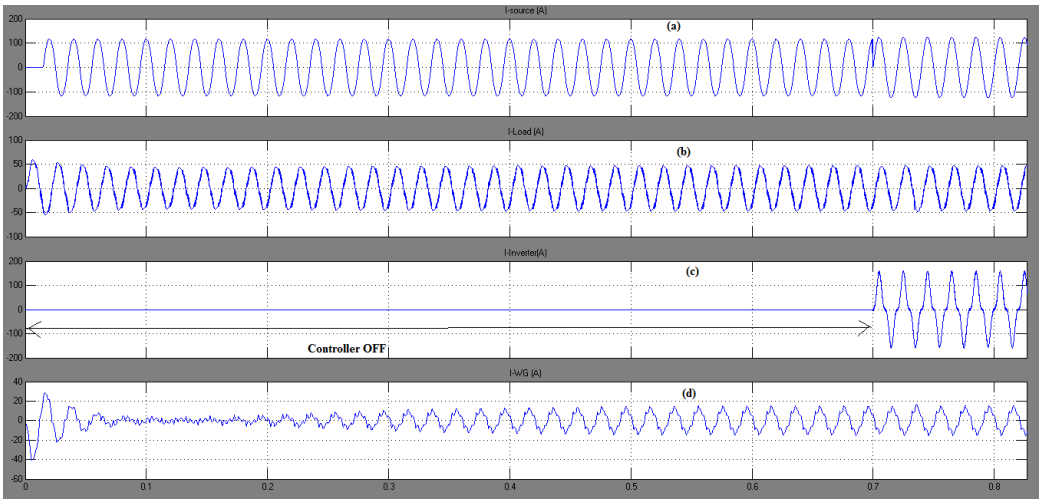


Fig.11 (a)Source current. (b)Load current. (c) Inverter injected current. (d)Wind generator(Induction generator)current

Grid having the nonlinear load is connected to wind energy generating system. The performance of the system is measured by switching the STATCOM at time s in the system and how the STATCOM responds to the step change command for increase in additional load at 0.1 s is shown in the simulation. When STATCOM controller is made ON, without change in any other load condition parameters, it starts to mitigate for reactive demand as well as harmonic current. The dynamic performance is also carried out by step change in a load, when applied at 1.0 s. This additional demand is fulfill by STATCOM compensator. Thus, STATCOM can regulate the available real power from source. The result of source current, load current are shown in Fig.11 (a) and (b) respectively. While the result of injected current from STATCOM are shown in Fig.11 (c) and the generated current from wind generator at PCC are depicted in Fig.11 (d).

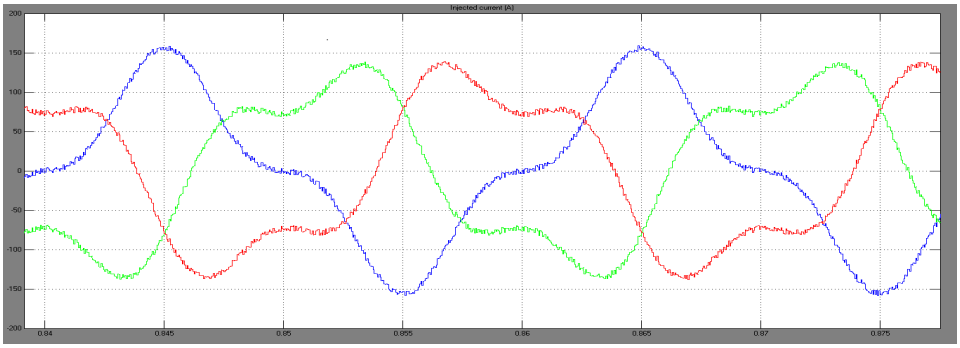


Fig.12 Enlarged view of 3-phase injected inverter current

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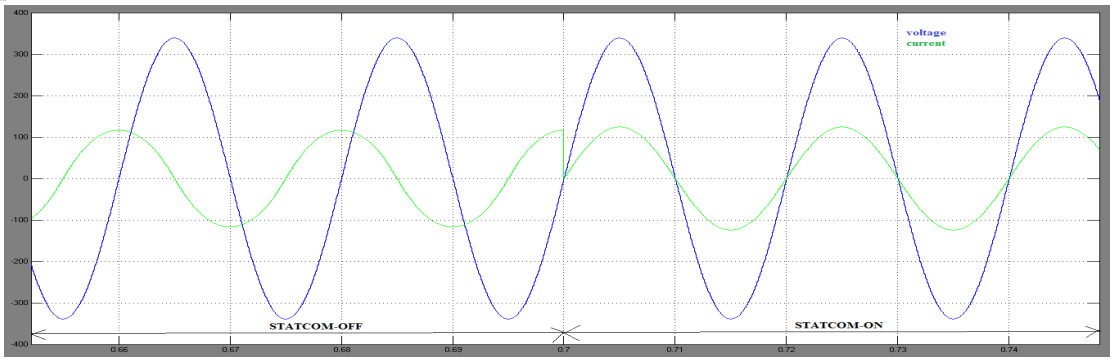


Fig.13 Supply voltage and current at PCC

The dynamic load does affect the inverter output voltage. The source current with and without STATCOM operation is shown in Fig.13. This shows that the unity power factor is maintained for the source power when the STATCOM is in operation.
FFT Analysis of current waveform in the Existing PI controller acting on the STATCOM at time 0.3 sec when the STATCOM is in OFF mode is shown in figure below. The THD obtained is 4.07%.

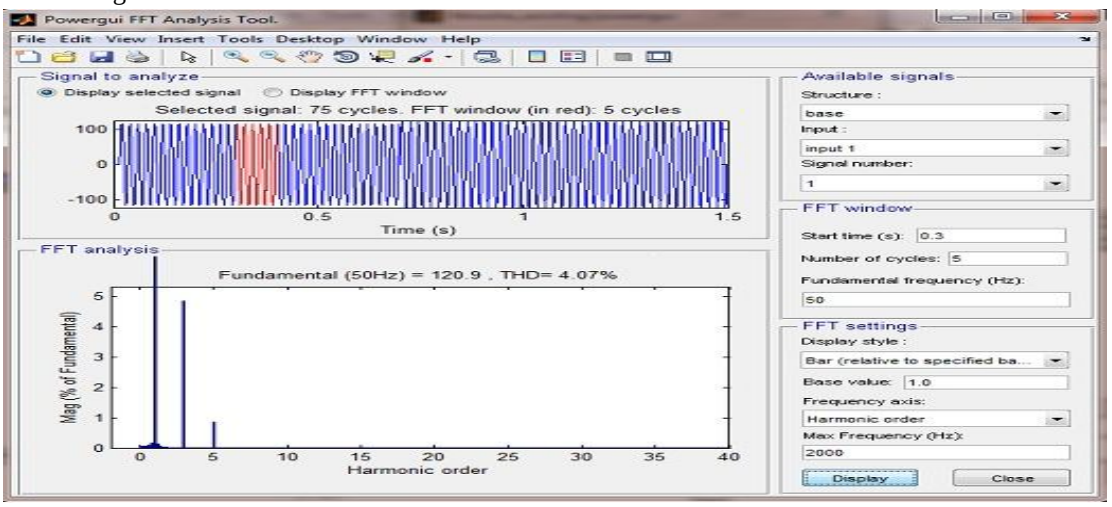


Fig.14 FFT analysis using existing PI controller (a) Source current (b) FFT of source current

FFT Analysis of current waveform in the Existing PI controller acting on the STATCOM at time 0.8 sec when the STATCOM is in ON mode is shown in figure below. The THD obtained is 0.41%.

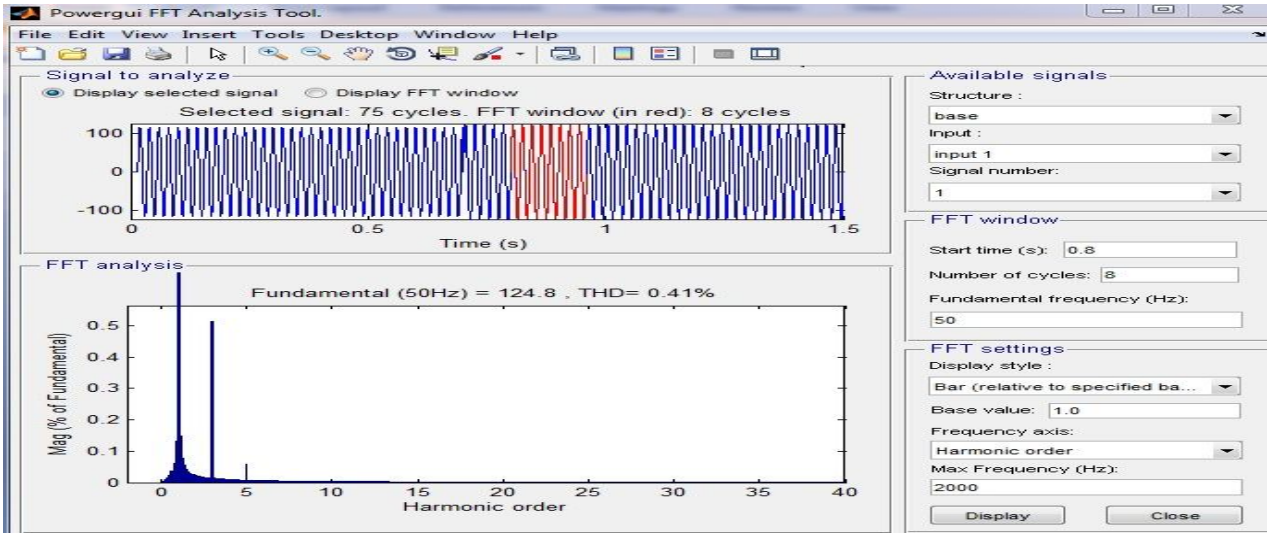


Fig.15 FFT analysis using PI controller (a) Source current (b) FFT of source current

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FFT Analysis of current waveform in the Fuzzy logic controller acting on STATCOM at time 0.1sec when the STATCOM is in OFF mode is shown in figure below. The THD obtained is 4.06%.

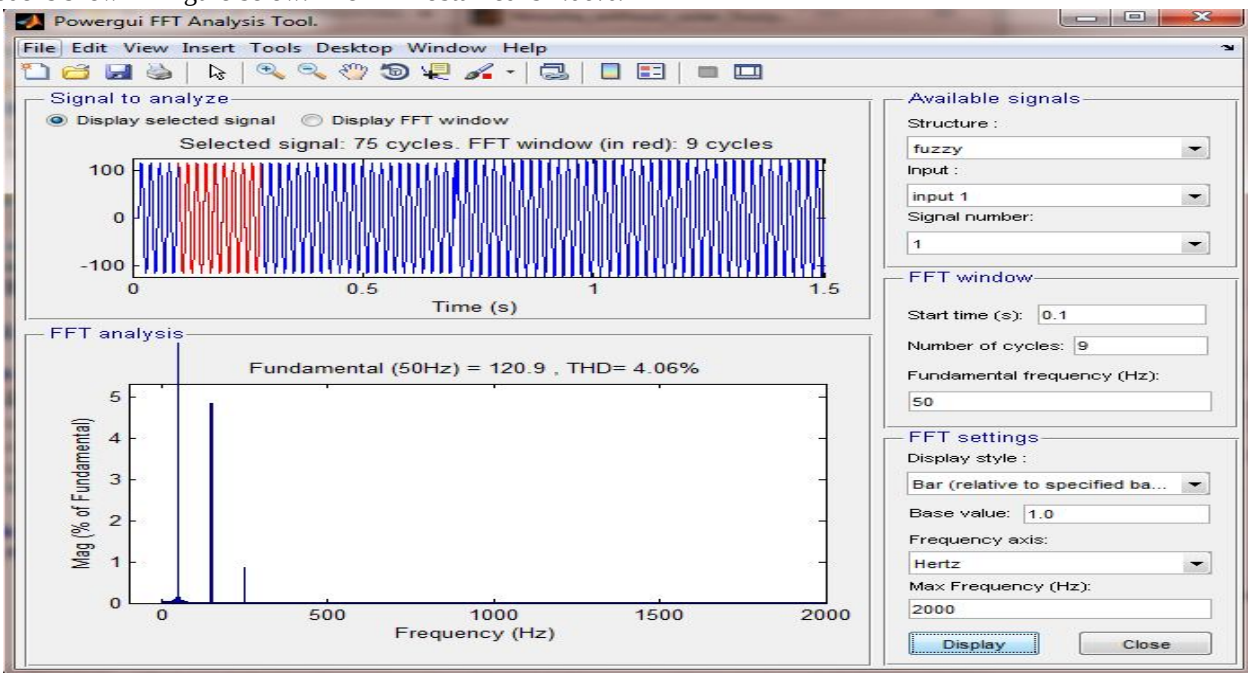


Fig.16 FFT analysis using Fuzzy logic controller (a) Source current. (b) FFT of source current.

FFT Analysis of current waveform in the Fuzzy logic controller acting on STATCOM at time 0.9 sec when the STATCOM is in ON mode is shown in figure below. The THD obtained is 0.38%.

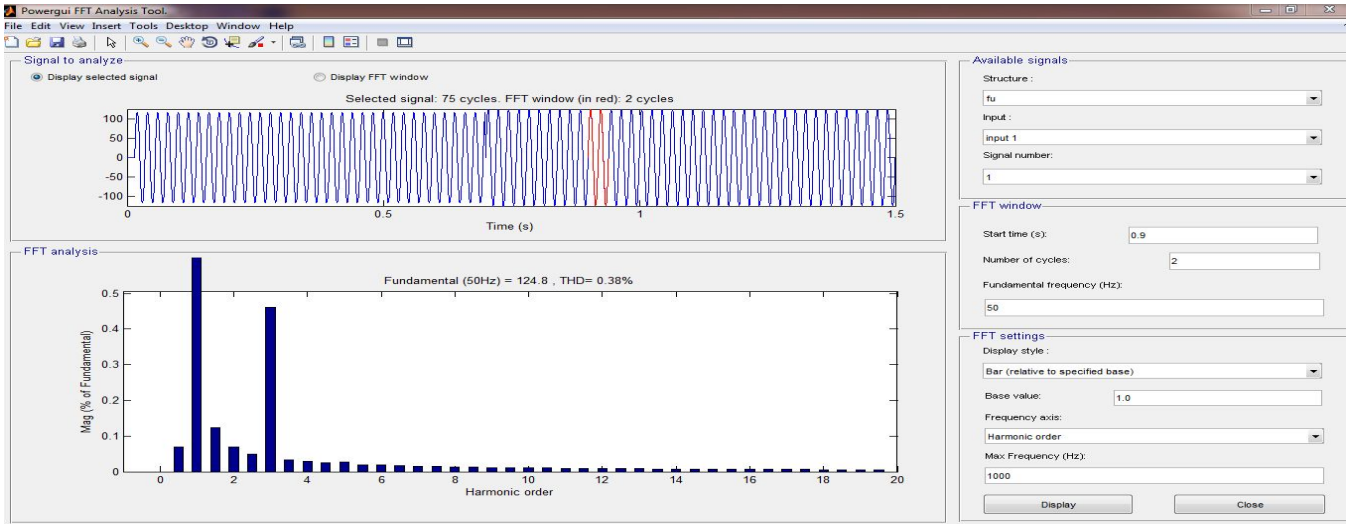


Fig.15 (a) Source current. (b) FFT of source current

Table II Comparison Of Thd Between Existing System And Proposed System:-

SYSTEM	STATCOM OFF	STATCOM ON
EXISTING SYSTEM	4.07%	0.41%
PROPOSED SYSTEM	4.06%	0.38%

In thesis the Existing PI controller acting on the STATCOM obtains THD value of 0.41 where in the fuzzy logic controller acting on the STATCOM obtained THD is 0.38 which is improved by using non linear variable gain fuzzy logic controller.

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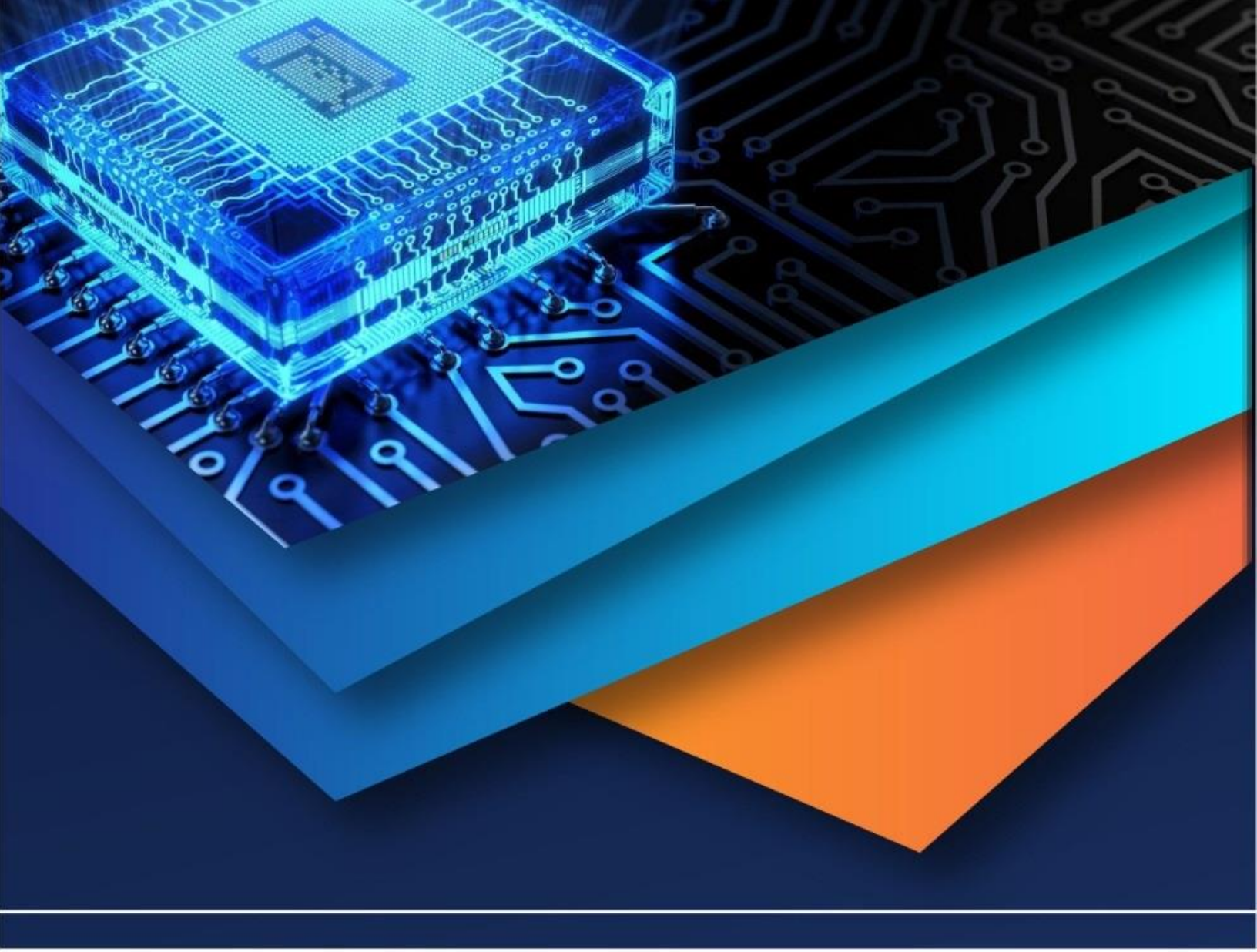
VI. CONCLUSION

The power quality issues and its consequences are presented. STATCOM has a capability to cancel out the harmonic parts of the load current. STATCOM maintains the source voltage and current in-phase and support the reactive power demand for the wind generator and load at PCC. Thus the proposed scheme fulfils the power quality norms as per the IEC standard 61400-21.By using fuzzy logic controller, total harmonic distortion and power quality has been improved.

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